Sensitivity of brake squealing concerning scattered component, joint and bearing properties

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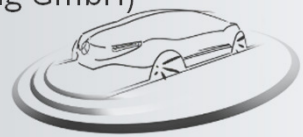


Agenda

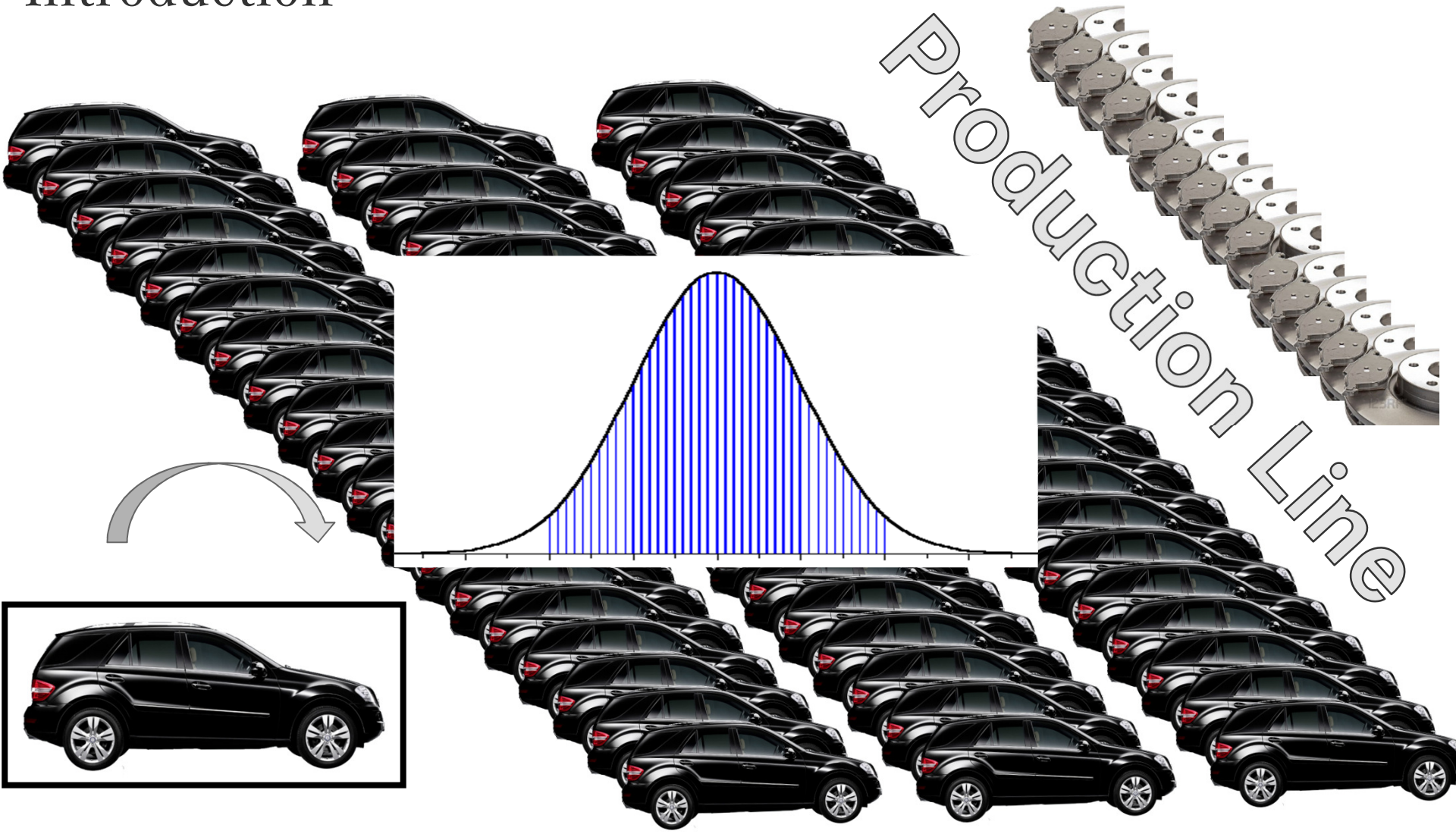
1 Simulation, Bench and Vehicle

2 NVH - Target

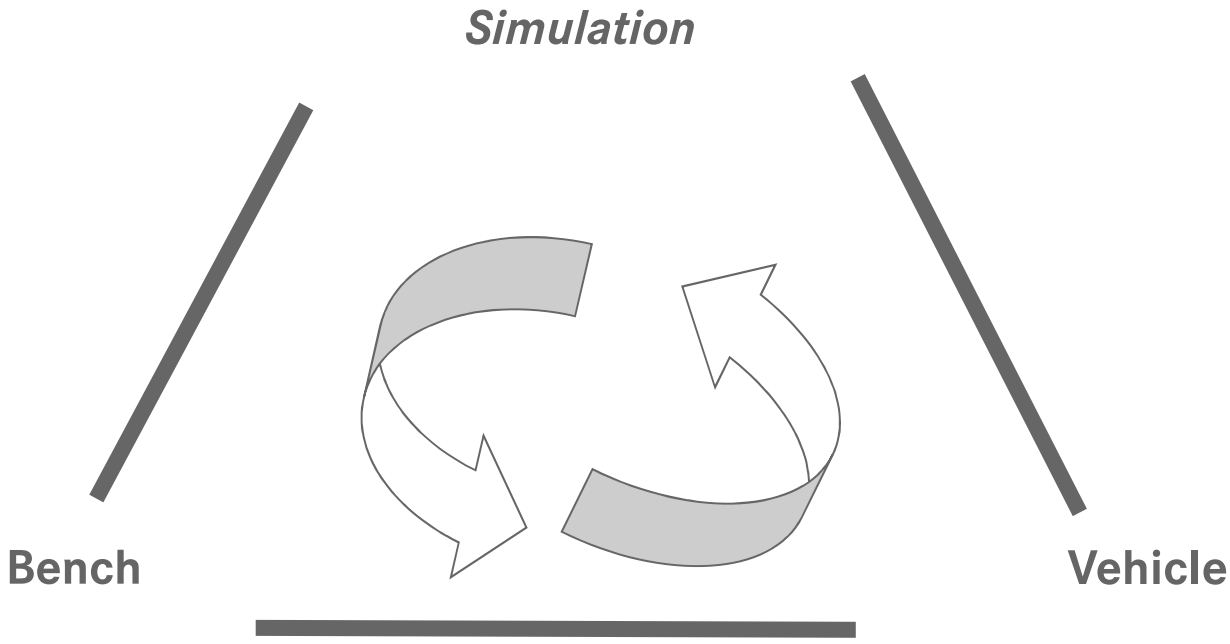
3 NVH – Squealing Joints Influence

4 Summary

Introduction



Simulation, Bench and Vehicle (Interdisciplinary Strategy: Cross Correlation Simulation, Bench and Vehicle)



✓ **Quality Control regarding Brake disc** Eigenfrequency, lining material, etc.

Source: EuroBrake 2012

Uncertain Parameters: E-Modulus, Material Density and Geometry (for example Knuckle)

Operating Points

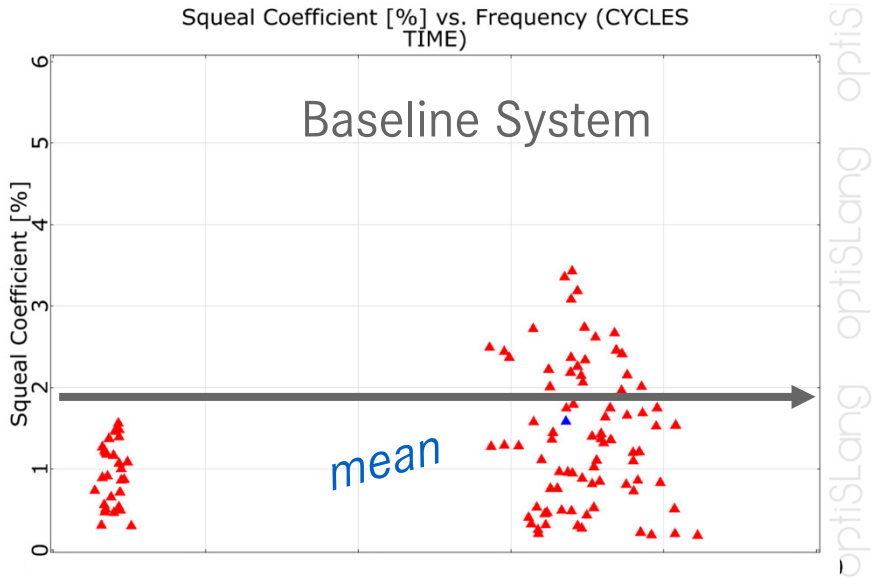
Material (Lininig material, Disc, Caliper, Axle, Shim and so on)

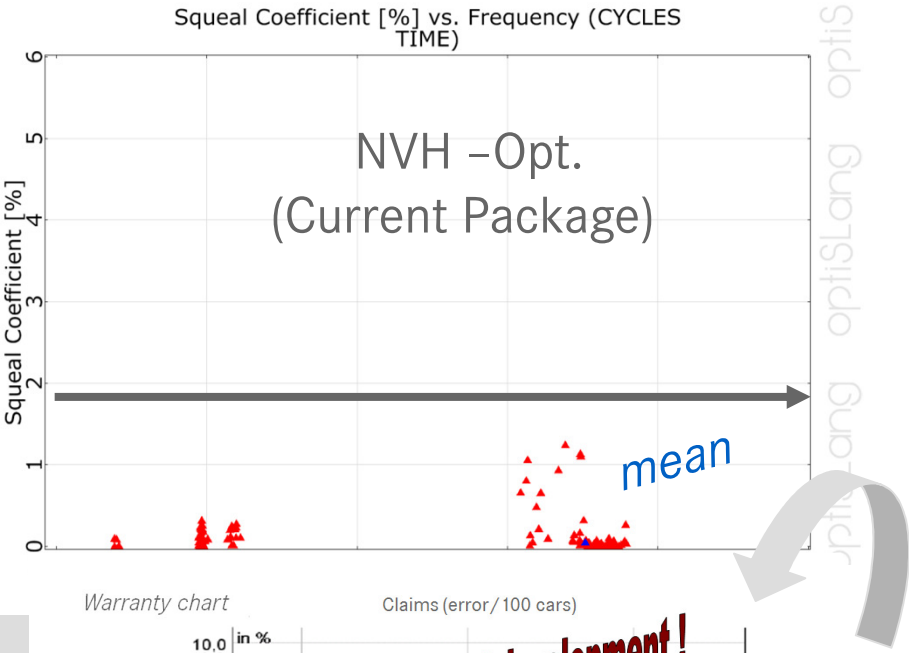
Geometry

#	Name	Distribution	Mean	CoV	Stddev	Lower Cut	Upper Cut	Format	Active	Constant
1	friction_disc_pad	Uniform	0.6	0.09622504486493...	0.05773502691896...	0.5	0.7	%20.13e	☑	☐
2	ROTATING_VELOCIT...	Uniform	2.5	0.34641016151377...	0.86602540378443...	1.0	4.0	%20.13e	☑	☐
3	OPERATING_PRESSURE	Uniform	10250.0	0.5491868414242782	5629.165124598851	500.0	20000.0	%18.11e	☑	☐
4	DISK	Uniform	9.75E7	0.07401926528072...	7216878.364870323	8.5E7	1.1E8	%14.7e	☑	☐
5	E1_Pad	Normal	1.289E7	0.1	1289000.0	-	-	%20.13e	☑	☐
6	E3_Pad	Uniform	750000.0	0.19245008972987...	144337.567297406...	500000.0	1000000.0	%20.13e	☑	☐
7	SHIM_ADHESIVE	Normal	500000.0	0.01	5000.0	-	-	%9.2f	☑	☐
8	SHIM_ELASTOMERE	Normal	5000000.0	0.01	50000.0	-	-	%20.13e	☑	☐
9	SHIM_STEEL	Normal					-	%20.13e	☑	☐
10	AL	Normal					-	%20.13e	☑	☐
11	AL_KNUCKLE	Normal					-	%20.13e	☑	☐
12	AL_TCA	Normal					-	%20.13e	☑	☐
13	AL_SUSPENSION	Normal					-	%20.13e	☑	☐
14	Caliper	Normal					-	%20.13e	☑	☐
15	inner_shoe	Normal					-	%20.13e	☑	☐
16	outer_shoe	Normal					-	%20.13e	☑	☐
17	Anchor	Normal					-	%20.13e	☑	☐
18	Steel	Normal					-	%11.5e	☑	☐
19	ST100C6	Normal					-	%11.5e	☑	☐
20	D4512	Normal					-	%12.2f	☑	☐
21	Piston	Normal					-	%11.2f	☑	☐
22	SHIM_ADHESIVE_RHO	Normal					-	%10.4e	☑	☐
23	SHIM_ELATOMERE_R...	Normal					-	%10.4e	☑	☐
24	SHIM_STEEL_RHO	Normal					-	%10.4e	☑	☐
25	AL_RHO	Normal					-	%10.4e	☑	☐
26	AL_KNUCKLE_RHO	Normal					-	%10.4e	☑	☐
27	AL_TCA_RHO	Normal	2.7E-6	0.01	2.7E-8	-	-	%10.4e	☑	☐
28	AL_SUSPENSION_RHO	Normal	2.7E-6	0.01	2.7E-8	-	-	%10.4e	☑	☐
29	DISK_RHO	Normal	7.035E-6	0.01	7.035E-8	-	-	%9.3e	☑	☐
30	Caliper_RHO	Normal	7.03E-6	0.01	7.03E-8	-	-	%10.4e	☑	☐
31	Piston_RHO	Normal	2.09E-6	0.01	2.09E-8	-	-	%10.4e	☑	☐
32	inner_shoe_rho	Normal	7.8E-6	0.01	7.8E-8	-	-	%10.4e	☑	☐
33	outer_shoe_rho	Normal	7.8E-6	0.01	7.8E-8	-	-	%10.4e	☑	☐
34	Anchor_RHO	Normal	7.295E-6	0.01	7.295E-8	-	-	%9.3e	☑	☐
35	D4512_RHO	Normal	7.2E-6	0.01	7.2E-8	-	-	%7.1e	☑	☐
36	Lining_RHO	Normal	2.57E-6	0.01	2.57E-8	-	-	%8.2e	☑	☐
37	ST100C6_RHO	Normal	7.82E-6	0.01	7.82E-8	-	-	%11.5e	☑	☐
38	KNUCKLE_SHAPE1	Uniform	0.5	0.5773502691896258	0.28867513459481...	0.0	1.0	%6.4f	☑	☐
39	KNUCKLE_SHAPE2	Uniform	0.5	0.5773502691896258	0.28867513459481...	0.0	1.0	%6.4f	☑	☐

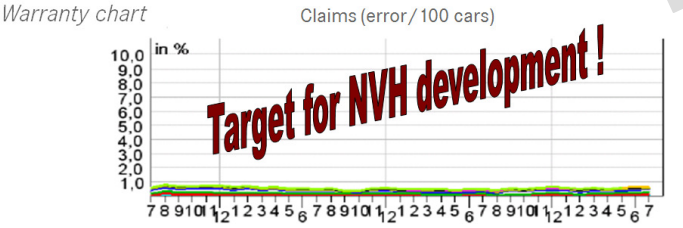
Notice: Factor 1 means 0.8 to 1.5 mm tolerance

Robustness Analysis Combined with Optimization Strategy (120 Designs – Complex Eigenvalue Analysis)





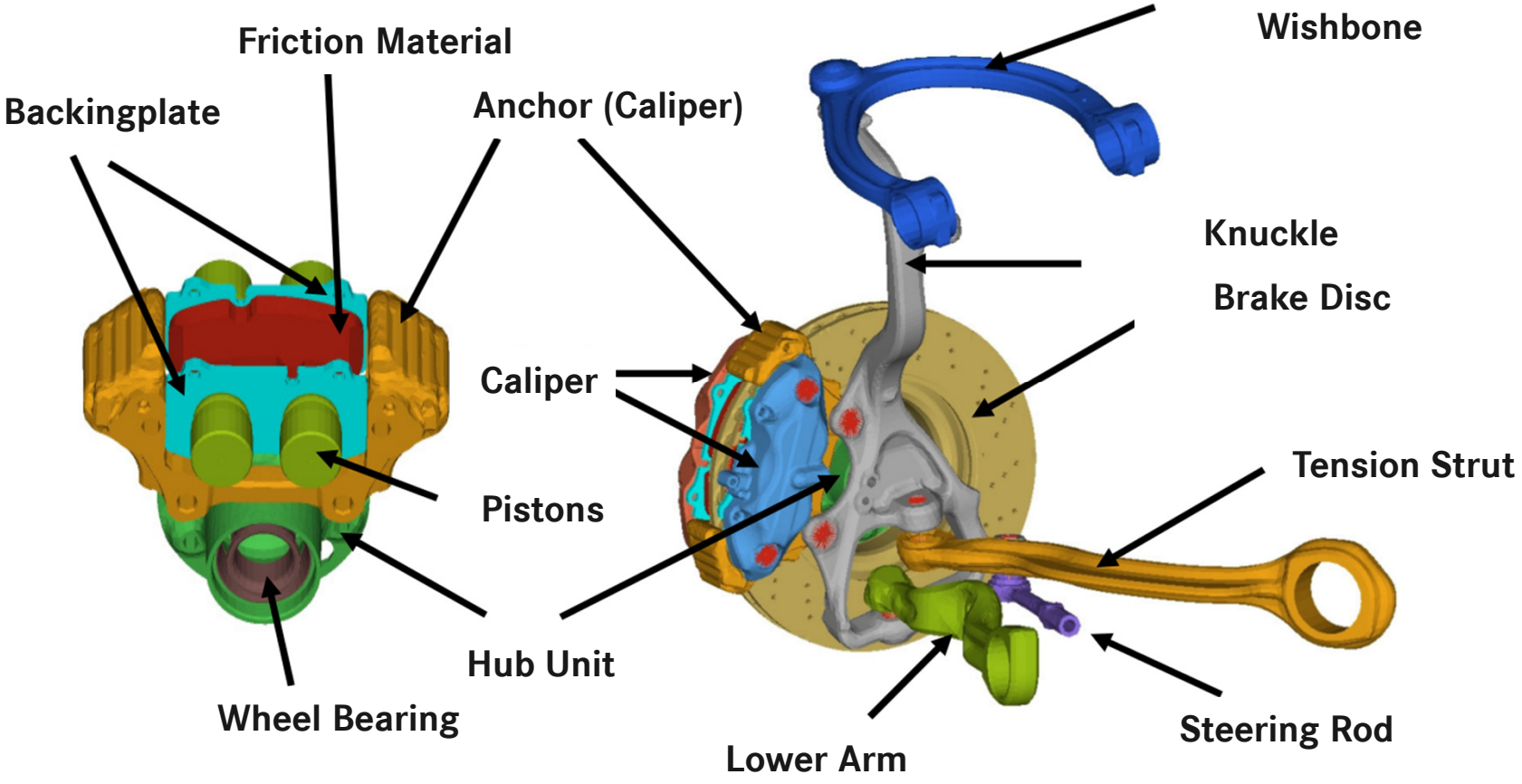
NVH - Target : Focus to find out the best solution taking into account the influence of uncertain parameters



....you get ideal curves with constant slopes at low percentage values

NVH – Squealing Joints Influence

CAD Model – Car Brake and Suspension



Background: Brake Squeal Analysis

Mathematical Equations

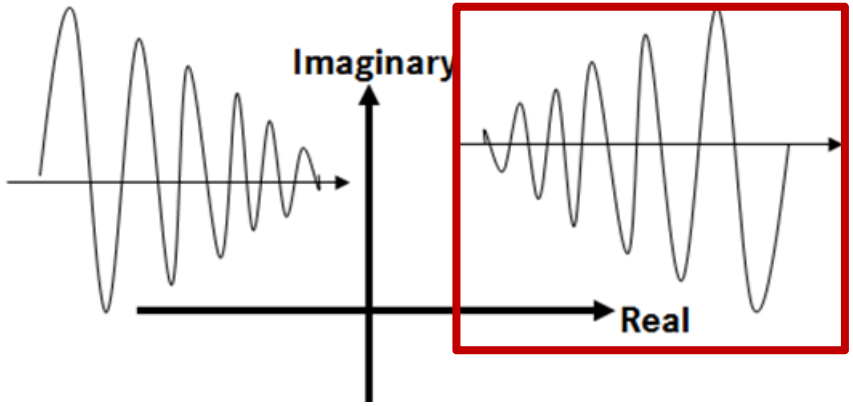
- $[M\lambda + D\lambda + C]\{\omega\} = 0$
- $\lambda = \propto \pm i\omega$

α = Real Part

ω = Imaginary Part (Squeal Frequency)

Complex Eigenvalue Analysis (CEA)

- $\mathbf{x(t) = A * e^{\lambda t} = A * e^{(\propto \pm i\omega)t}}$
  $\mathbf{= e^{\alpha t}(A1 * \cos \omega t + A2 * i\sin \omega t)}$



Stable / Unstable – Evaluation of complex Modes

- $\alpha < 0$ System is stable
- $\alpha > 0$ System not stable

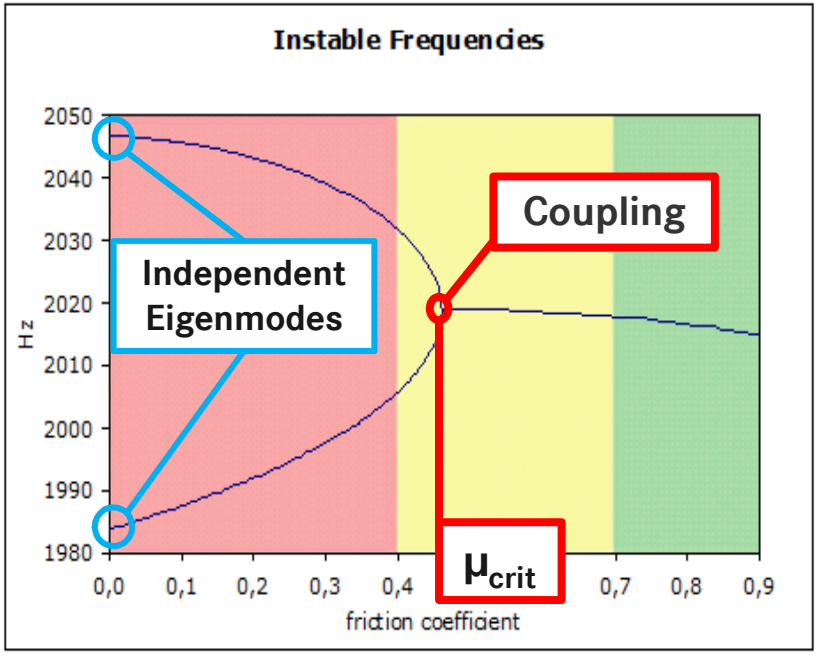
Positive α indicates a system behavior with an increasing amplitude of the brake oscillation

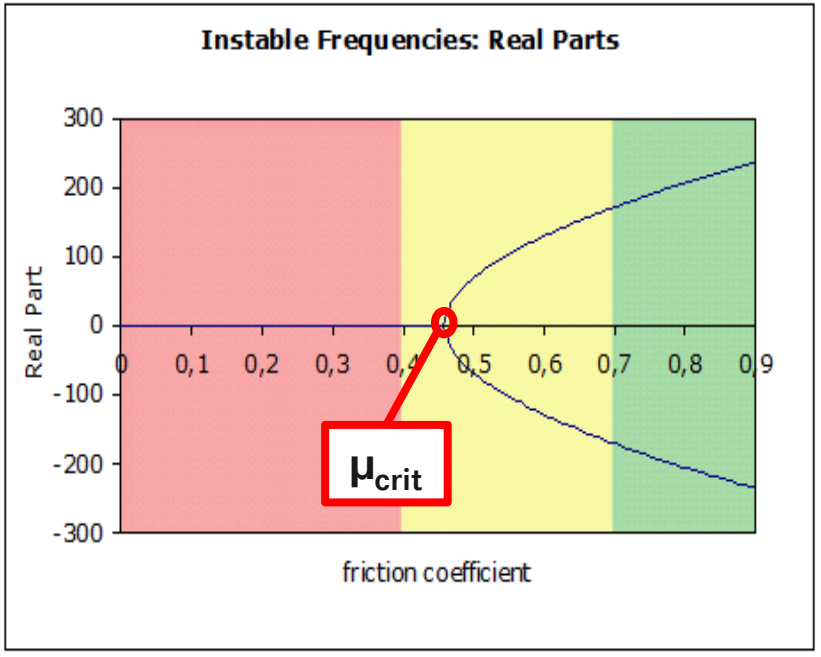
Background: Complex Eigenvalue Analysis

- Without Friction: Independent Eigenmodes
- Convergence of Eigenfrequencies with increasing μ

➢ Mode Coupling at μ_{crit}

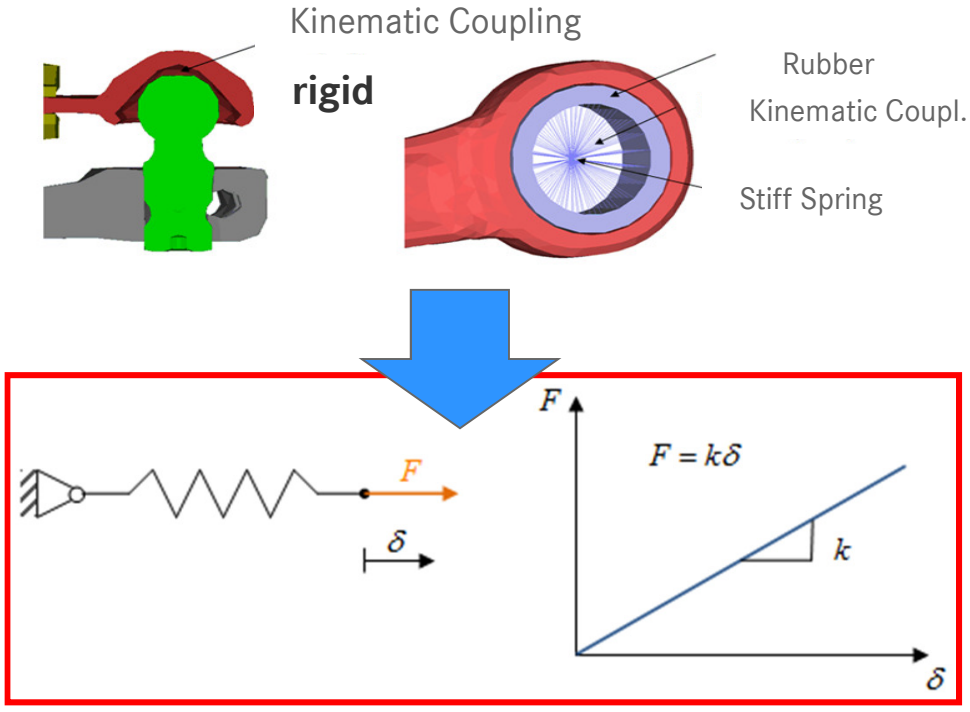
➢ **Unstable System (Squealing Propensity)**

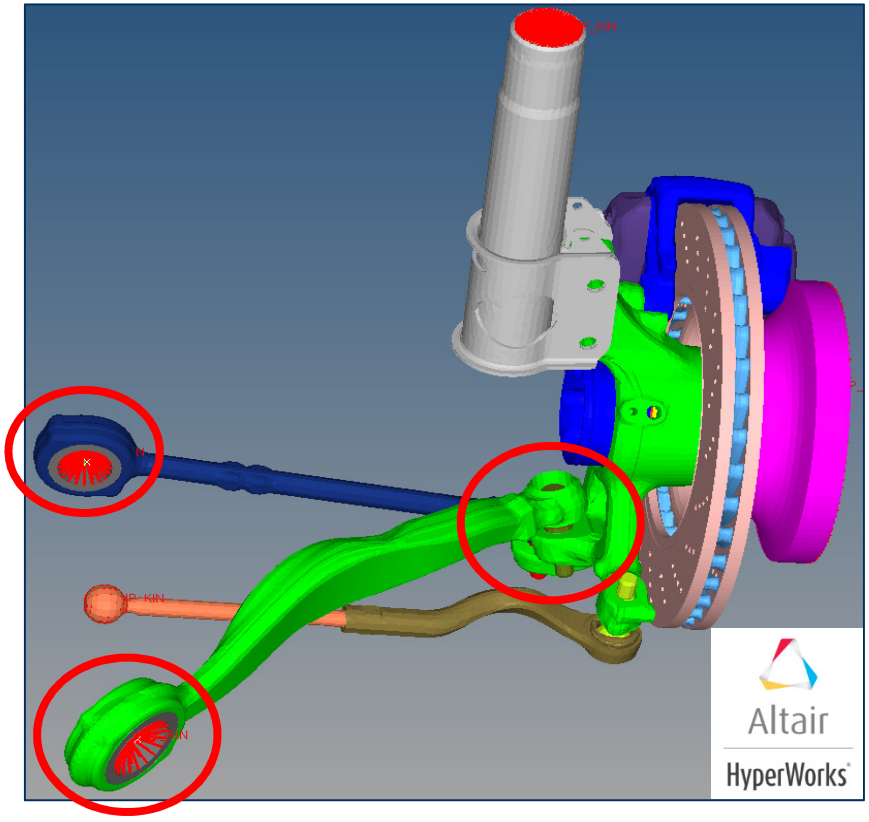




Joints Modeling

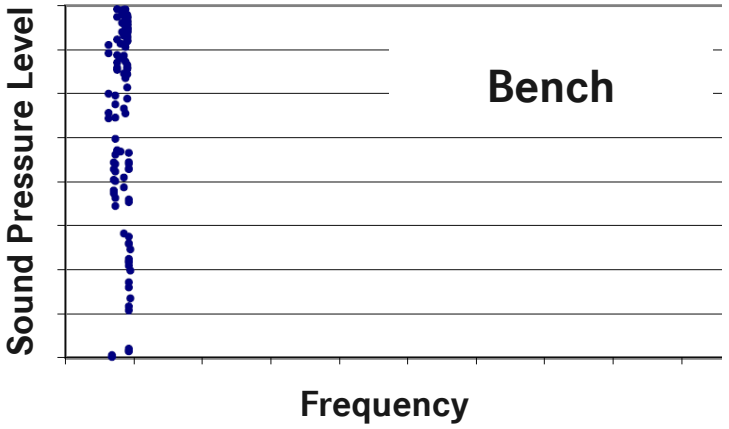
- Bearings, Ball Joints and Kinematic Description





Bench Test – Noise Problem

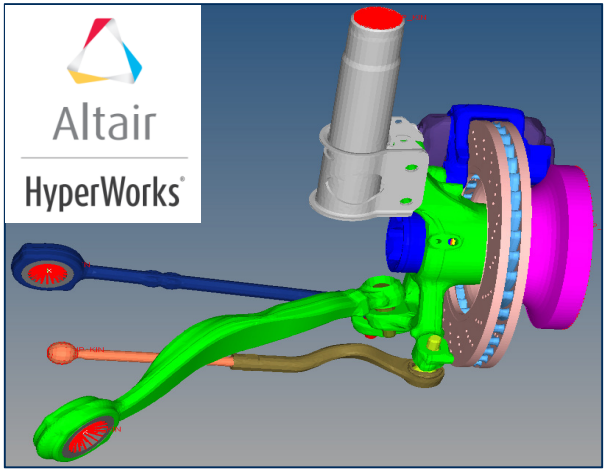
- Noise problem identified



- **Deterministic FE simulation was not able to find the critical frequency !!**

➢ Sensitivity Analysis

Ball Joints, Bearings stiffness
Pad and Disc stiffness/Geometry
Brake Pressure

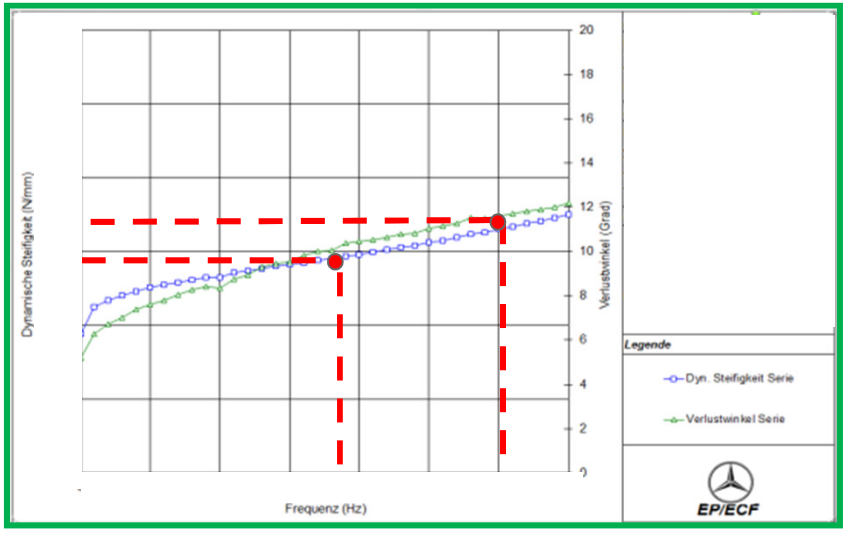


Material Behavior in CEA

- Complexe Eigenvalue Analysis investigates **Stationary System**

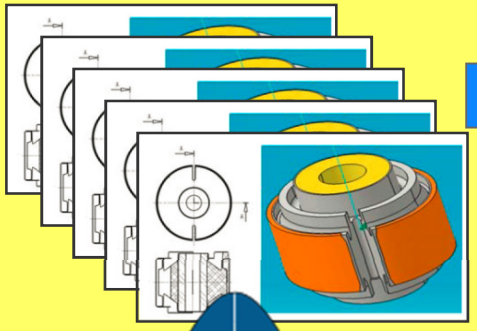
$$[Mp^2 + Cp + K]\{u\} = 0$$

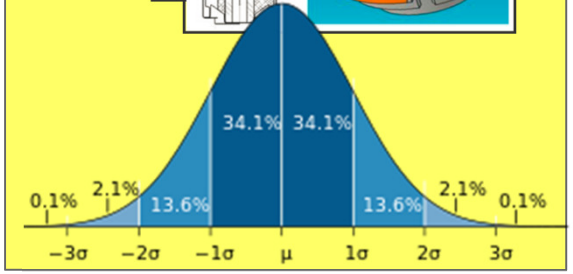
- Frequency, amplitude and temperature depending behavior not considered in single Calculation



Workflow: Sensitivity Analysis

Variation of Material and Geometry





FEM Process

Stable?
→ Calculation

$$[M\lambda + D\lambda + C]\{\omega\} = 0$$

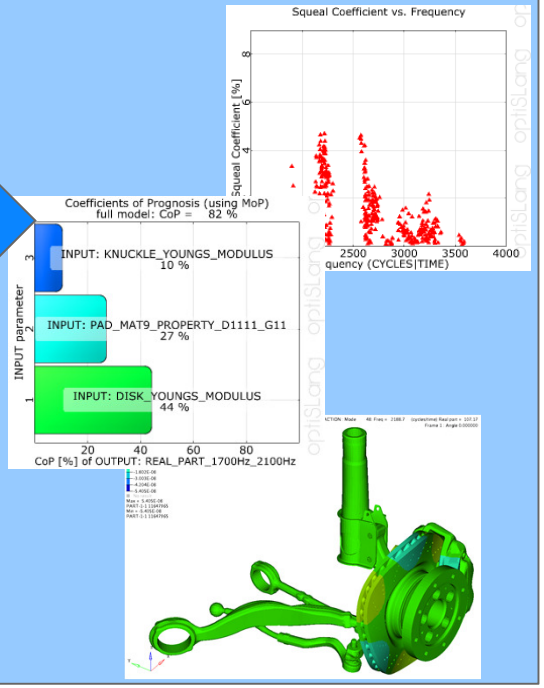
$$\lambda = \propto \pm i\omega$$

α = Real Part

ω = Imaginary Part

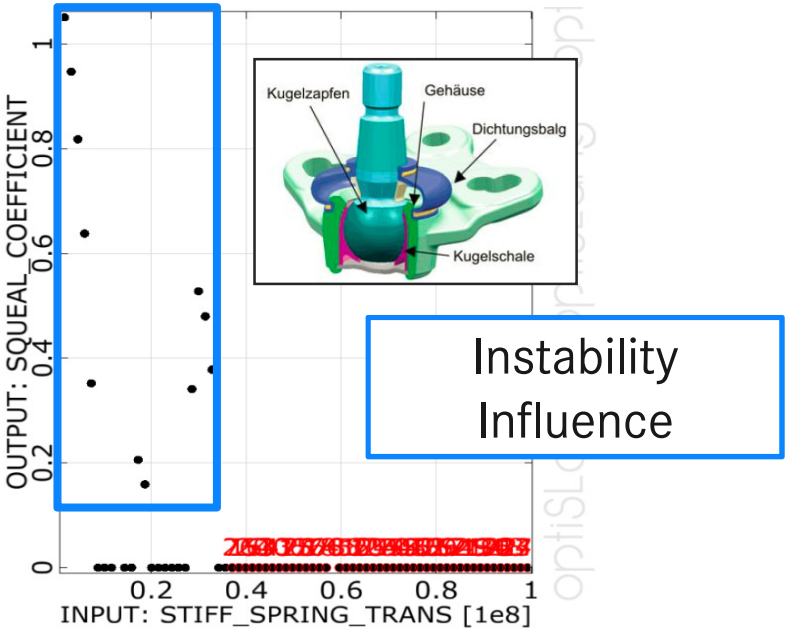
Post Processing

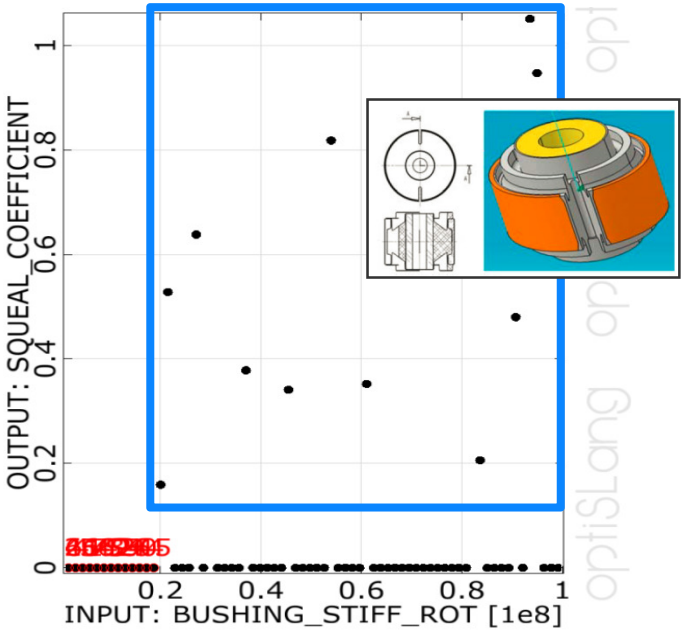
Statistical Evaluation of the Analysis



Sensitivity Analysis: Joints Influence

- Dynamic Measurements Available: Ball joints and Bearings
- **Sensitivity Analysis was adopted in order to identified the influence of Joint stiffness to the noise problem**

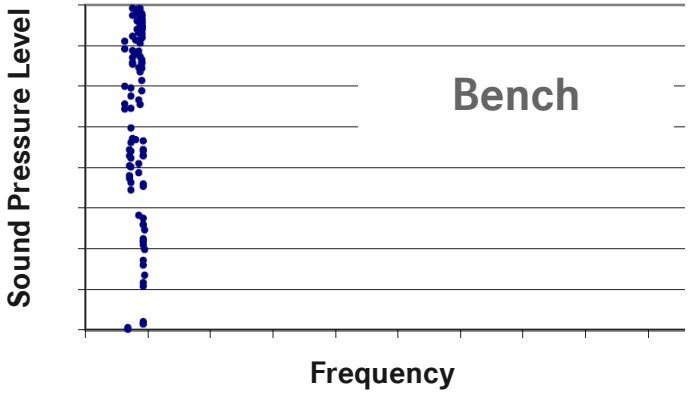


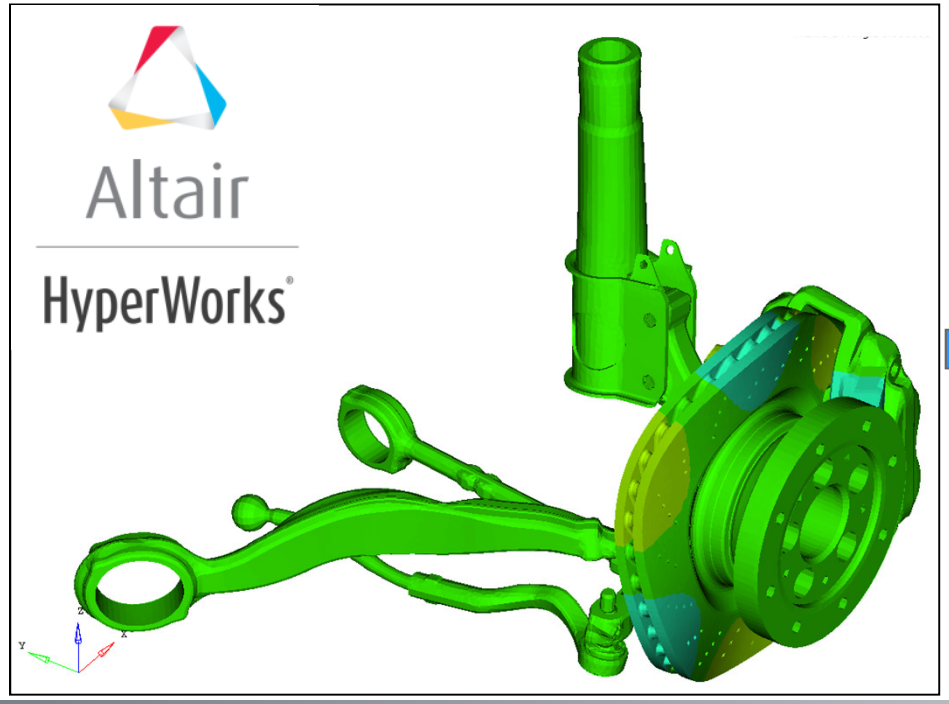


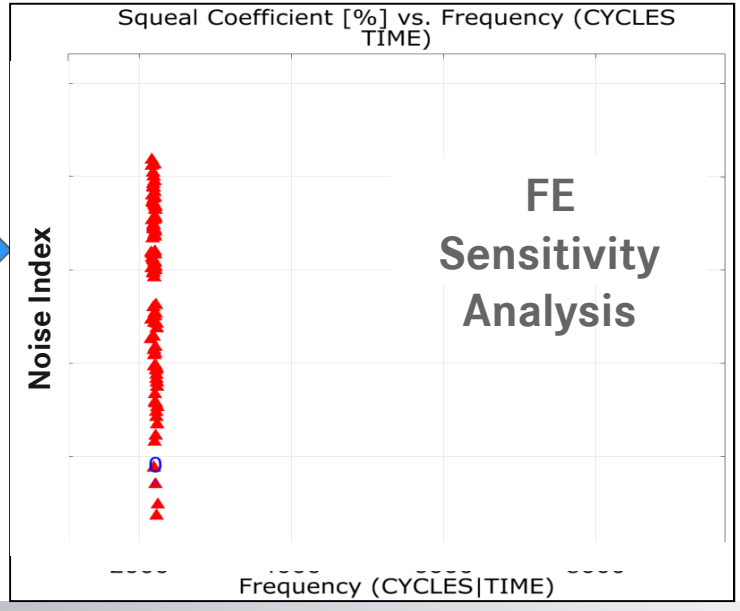
Source: Christian Büttner

Bench and Sensitivity Analysis Validation

- Frequency identified
- Additional optimization to fix the problem

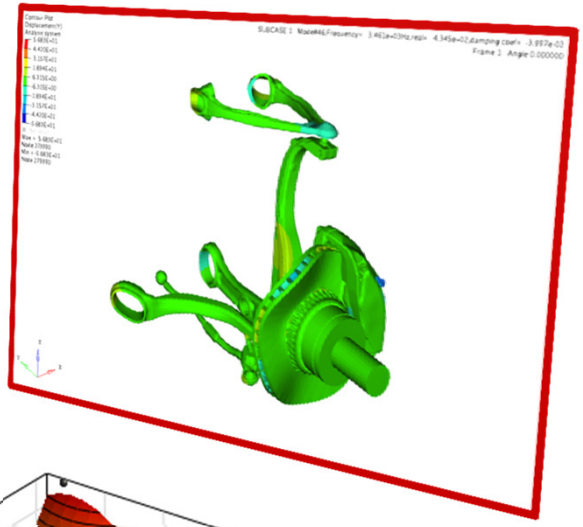


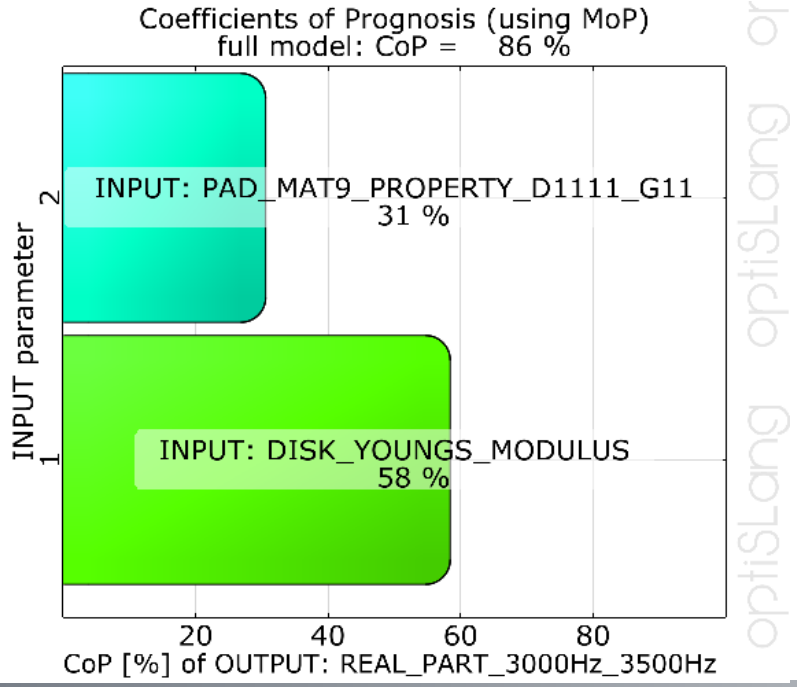


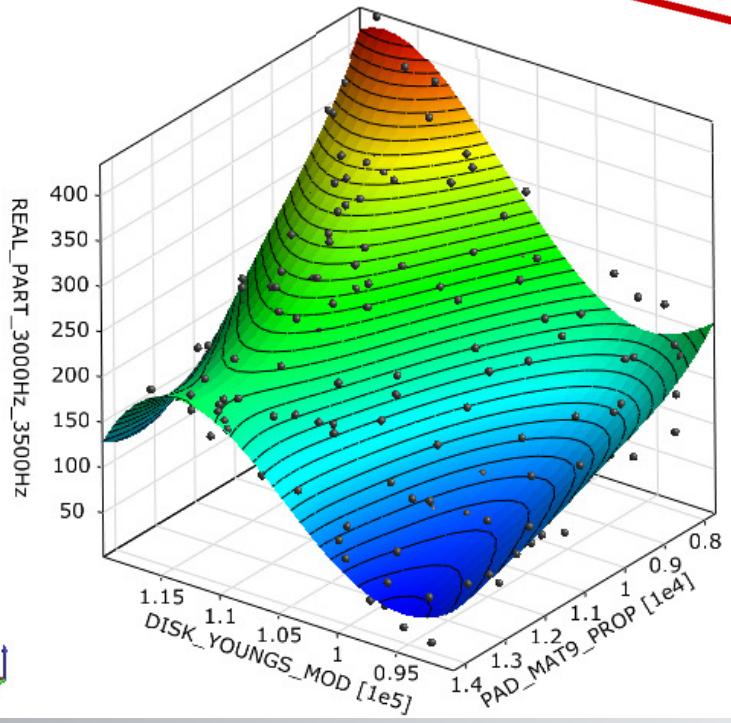


Model Improvements

- Better Identification of main influences and local minimum / maximum
- Better prediction of system behavior

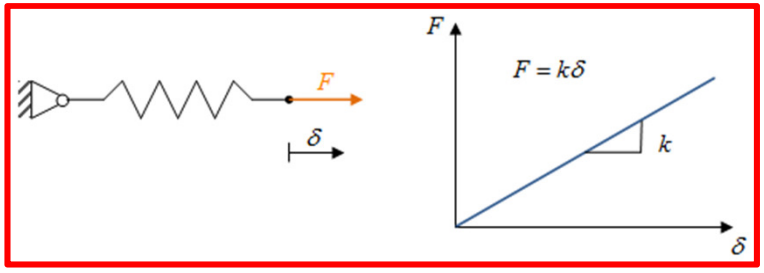


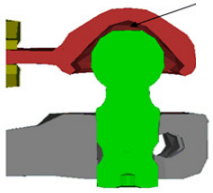




Conclusion

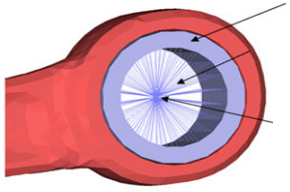
- Improvements in Modelling Brake System
  - Better Identification of main influences
  - Better prediction of system behavior
  - Results fitting better with bench vehicles





rigid

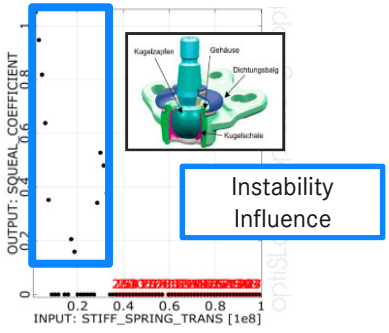
Kinematic Coupling

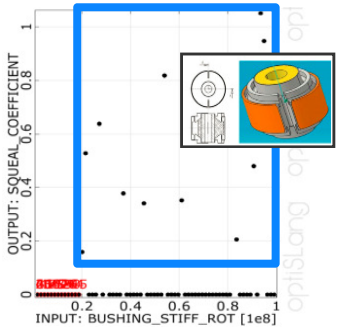


Rubber
Kinematic Coupling

Stiff Spring

- Using Sensitivity Analysis
  - Identification of ideal parameter range
  - Joint parameters haven‘t a strong influence





Mercedes-Benz

Thank you for your attention !